TURKISH REPUBLIC OF NORTHERN CYPRUS
NEAR EAST UNIVERSITY
HEALTH SCIENCES INSTITUTE

COMPARING THE EFFECTS OF CAD/CAM NICKEL TITANIUM LINGUAL RETAINERS ON TEETH STABILITY AND PERIODONTAL HEALTH WITH CONVENTIONAL FIXED AND REMOVABLE RETAINERS: A RANDOMIZED CLINICAL TRIAL

MOHAMED BASEL ALRAWAS

PhD Thesis

Department of Orthodontics

Associate Professor Dr. ULAŞ ÖZ

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NICOSIA 2020

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LIST OF ABBREVIATIONS

CAD/CAM LR……………………… 0.012×0.018-in computer-aided design computer-aided manufacturing Nickel-titanium lingual retainer

MSLR …………………..0.017-in, twisted multi-stranded stainless-steel lingual wire

SSLR ……………… 0.027×0.011-in single strand Nickel-free Titanium lingual wire

VFR …………………………………………..Vacuum-formed removable retainer

(T_0) ……………………………………………...Immediately after the treatment

(T_1)……………………………………………….…Three months after the treatment

(T_2)…………………………………………….….Six months after the treatment

IR………………………………………………………... Irregularity index

ADAL……………………………………………..Anterior dental arch length

3-3……………………………………………………..Inter-canine width

6-6 ……………………………………………………..Inter-molar width

PI……………………………………………………………Plaque index

GI…………………………………………………………Gingival index

BOP………………………………………… Bleeding on probing

PD…………………………………………………………...Pocket depth

B………………………………………………………..Buccal surface

MB……………………………………………………Mesio-buccal surface

DB……………………………………………………..Disto-buccal surface

L………………………………………………………….Lingual surface

ML…………………………………………………Mesio-lingual surface

DL……………………………………………………..Disto-lingual surface

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CAD/CAM NIKEL TITANYUM LINGUAL RETAINERLERI DIŞ STABILITESI VE PERIODONTAL SAĞLIK ÜZERINDEKI ETKILERININ KONVANSIYONEL SABIT VE HAREKETLI RETAINERLERI KARŞILAŞTIRILMASI: RANDOMIZE KLINIK ÇALIŞMA

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Danışman: Doç. Dr. Ulaş ÖZ

Bölüm: Department of Orthodontics

ÖZET

Amaç: Bu çalışmanın amacı, bir CAD / CAM Nikel-Titanyum tutucunun mandibular ön dişlerin stabilitesi ve periodontal sağlık üzerindeki etkisini değerlendirmek ve diğer tutucularla karşılaştırılmasıdır.

Ortam/Evren ve Örneklem: Her iki cinsiyetten ortodontik tedaviden önce düzensizlikleri olan ve tam sabit cihazlarla mekanoterapi ile tedavi edilen 60 katılımcı çalışmaya dahil edilerek rastgele dört gruba ayrılmıştır: CAD / CAM NiTi, çok telli paslanmaz çelik, tek telli nikel içermeyen titanyum dil tutucular ve vakumla oluşturulmuş çıkarılabilir tutucu. Katılımcıların tedavi sonunda ortalama yaşı yaklaşık 20 yıldır.

Araçlar ve Yöntem: Tüm katılımcılar için üç farklı zamanda dijital ölçüler alınmıştır: tedaviden hemen (T_0), üç ay (T_1) ve altı ay (T_2) sonra. Alt ön dişlerdeki düzensizlikler, köpek dişler arası ve molar arası genişlik ve ark uzunluğu 3Shape Ortho Viewer yazılımı kullanılarak kaydedilmiştir. Ek olarak plak indeksi, gingival indeks, sondalamada kanama ve cep derinliği T_2'de değerlendirilmiştir. **Bulgular:** altı aylık takip süresince tüm gruplarda alt ön dişlerde bir miktar nüks görülmüştür. Ön diş düzensizlikleri, köpek dişler arası ve molar arası genişlik ve ark uzunluğu açısından gruplar arası istatistiksel fark bulunmamıştır. Bununla birlikte, çok telli paslanmaz çelik grubunda, köpekler arası genişlik, istatistiksel bir farkla 0,10 mm azalmıştır (P = 0,048). Artan kavis uzunluğu ile ilgili olarak tek iplikli Nikel içermeyen Titanyum grubu içinde (P = 0.045) ile ek istatistiksel fark bulunmuştur. Mandibular ön dişler, plak indeksi, gingival indeks, sondalamada kanama ve cep derinliği açısından klinik olarak anlamlı farklılıklar göstermemiştir. **Sonuç:** CAD / CAM NiTi tutucusu ve diğer tutucular arasında klinik başarısızlık oranı açısından istatistiksel bir önem bulunmamıştır. CAD / CAM lingual tutucu, diğer tutucu tiplerine kıyasla daha az plak birikimi ve dişeti iltihabı göstermiştir. Ayrıca, bu kısa süreli çalışmada periodontal sağlık üzerinde klinik olarak anlamlı bir etki yapmadığı görülmektedir.

ANAHTAR KELİMELER
Koruyucu, CAD / CAM, Kesiciler, Düzensizlik, Periodontal sağlık.

COMPARING THE EFFECTS OF CAD/CAM NICKEL TITANIUM LINGUAL RETAINERS ON TEETH STABILITY AND PERIODONTAL HEALTH WITH CONVENTIONAL FIXED AND REMOVABLE RETAINERS: A RANDOMIZED CLINICAL TRIAL

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ABSTRACT

Objective: The objectives of this study were to evaluate the effect of a CAD/CAM Nickel-Titanium retainer on the stability of mandibular anterior teeth and periodontal health and to compare it with multi-stranded stainless-steel, single-stranded nickel-free titanium lingual retainers, and vacuum-formed removable retainer.

Setting/Sample Population: 60 participants from both genders who had irregularities prior to orthodontic therapy and who had been treated with full-fixed orthodontic appliances were included in the study and randomly allocated into four groups: CAD/CAM NiTi, multi-stranded stainless-steel, single-stranded nickel-free titanium lingual retainers, and vacuum-formed removable retainer. The mean age of the participants at the end of the treatment was approximately 20 years.

Materials and Methods: Digital impressions was taken for all participants at three different times: immediately after orthodontic debonding (T_0), three months (T_1), and six months (T_2) after treatment. Irregularities of the lower anterior teeth, inter-canine and inter-molar width, and arch length were recorded using 3Shape Ortho Viewer software. Additionally, plaque index, gingival index, bleeding on probing, and pocket depth was assessed at T_2. **Results:** during the six-month follow-up, all groups had shown some relapse in the lower anterior teeth. No statistical difference was found intergroup in terms of anterior teeth irregularities, inter-canine and inter-molar width, and arch length. However, within the multi-stranded stranded stainless-steel group, inter-canine width had decreased by 0.10mm with a statistical difference (P=0.048). Additional statistical difference with (P=0.045) was found within the single-stranded Nickel-free Titanium group regarding the increased arch length. The mandibular anterior teeth did not show any clinically significant differences intergroups, regarding the plaque index, gingival index, bleeding on probing, and pocket depth. **Conclusion:** No statistical significance was found between the CAD/CAM NiTi retainer and other retainers regarding to the clinical failure rate. The CAD/CAM lingual retainer showed less plaque accumulation and gingival inflammation compared with other retainer types. However, this does not appear to make a clinically significant affect to the periodontal health in this short-term study.

KEYWORDS

Retainer, CAD/CAM, incisors, irregularity, periodontal health.

1. INTRODUCTION

Maintaining the stability of orthodontic treatment outcomes remains a significant challenge in order to avoid treatment failure. Therefore, a retention stage is a critical step for each orthodontically treated case (Bibona et al., 2014; De Bernabé and Montiel-Company, 2017). According to previous clinical trials, it has been proven that the mandibular anterior teeth are the most susceptible to be relapsed (Freitas et al., 2004). Little (1975) found that the post-treatment irregularity of the lower anterior teeth is sufficient evidence for the appearance of other malocclusion tendencies. Additionally, 70% to 90% of cases have undergone some degree of relapsing in the mandibular teeth, while the maxillary teeth have shown a lower affection (Kaan and Madléna, 2001; Arn et al., 2020).

To resolve this issue, many appliances have been developed that retain the stability of the teeth at the retention phase. These appliances can be either removable appliances or fixed lingual retainers (Bearn, 1995). A systematic review concluded that the studies conducted in this area have not agreed about the most effective type of retainers and the appropriate duration of retention that preserves long-term stability of treatment outcomes (Vandevska-Radunovic et al., 2013; Littlewood et al., 2006). Atack et al. (2007) made a comparison between Hawley removable retainers and fixed lingual retainers and found that there was not a statistically significant difference between them. However, Al-Moghrabi et al. (2018) reached the opposite conclusion when comparing between Vacuum formed retainers and fixed lingual retainers, determining that the fixed lingual retainers are better for maintaining the stability of the lower anterior teeth. While searching for effective techniques for maintaining the treatment results, clinical trials and studies have encountered some disadvantages of both retainer types. For instance, greater failure rates and negative consequences have been observed due to some wire activation, which leads to incisor irregularities, spacing, and uncontrolled torque (Pazera et al., 2012; Lumsden et al., 1999). Furthermore, clinical studies have reported a failure percentage of fixed retainers ranging from 10.3% to 47% (Bearn, 1995). A research conducted by Freitas et al. (2004) showed that 1.95mm was the average relapse at the mandibular arch for non-extraction treatments. Other disadvantages include the increased probability of occlusal interference for the upper arch retainer, tongue irritation, and the increased complexity of oral hygiene process, which leads to plaque accumulation, gingival bleeding, recession and increasing in the pocket depth, which causes a decline in periodontal health (Kravitz et al., 2017; Corbett et al., 2015; Knaup et al., 2019). This last result caused by fixed retainers was indicated by Levin et al. Additionally, Al-Moghrabi et al. (2018) confirmed that long-term wear of either removable or fixed retainers causes the same level of gingival inflammation.

Since Zacchrisson conducted his clinical trials in 1977, the multi-stranded wire lingual retainers were considered to be the gold standard for maintaining the stability of anterior teeth after orthodontic treatment, which has led to the increased necessity of using lingual fixed retainers in orthodontic practices (Knaup et al., 2019; Zachrisson, 1977; Oshagh et al., 2014). This made it crucially important that a new type of fixed retainer be developed that is more effective and can overcome the aforementioned disadvantages. For this particular reason, the Computer-Aided Design and Manufacturing (CAD/CAM) Nickel-titanium lingual retainer was designed (Kravitz et al., 2017; Wolf et al., 2015). The CAD/CAM lingual retainer is digitally positioned, which gives it an individually optimized placement, greater fitting accuracy, and interproximal adjustment; therefore, it has less tongue irritability, better stability, and it can prevent occlusal interference. The Nickel-titanium rectangular wire has higher flexibility, which improves the physiological tooth movement and decreases the failure rate. Furthermore, the wire is electropolished which produces a smooth, polished, corrosion resistant wire that is bacterial and plaque accumulation resistant (Kravitz et al., 2017; Knaup et al., 2019; Möhlhenrich et al., 2018). These results were proven by the in vitro study done by (Möhlhenrich et al., 2018). Knaup et al. (2019) found that these retainers have more positive effects on oral health compared with the multi-stranded lingual fixed retainers.

Clinical trials and evidence that have proved the efficiency and the advantages of the CAD/CAM Nickel-titanium lingual retainer are still insufficient. Therefore, the present study aims to test the hypothesis that the CAD/CAM retainers can overcome the disadvantages of the other retainers, provide higher stability of the anterior teeth, and decrease the deterioration of periodontal health.

2. GENERAL INFORMATION

2.1. Relapse after orthodontic treatment

2.1.1 Relapse definition

Teeth tendency to return to its position before treatment, usually occurs in the mandibular anterior teeth (Yu et al., 2013).

2.1.2 Relapse etiology

Relapse has many causes that are hard to identify, however, researchers suggested four main causes for relapse:

- Occlusal.
- Periodontal and gingival.
- Growth.
- Soft tissues.
- Other factors of relapse (Mitchell, 2007).

Periodontal and gingival factors

Periodontal ligament and their related alveolar bone remodel when teeth are moved during and after orthodontic treatment. However, until the stretched periodontal fibers adjust to the new position, the stretched periodontal fibers cause a high tendency for the tooth to be pulled back to its original position particularly for rotated teeth. This remodel occurs within a month for the alveolar bone, 3-4 months for the principal fibers of PDL and slightly slowly for the gingival fibers, 4-6 months for the collagen fibers in the gingival, and more than 8 months for the Elastic fibers in the dento-gingival and interdental fibers (supra-crestal fibers) (Mitchell, 2007).

Occlusal factors

One of the most important steps for increasing the treatment outcomes stability is to bring the teeth to the fully interdigitated position at the finishing stage of the orthodontic treatment.

The occlusion settling can be achieved by:

1. Providing a smooth teeth movement by using a light vertical elastic force with light round wires at the finishing comprehensive orthodontic treatment stages.

2. Using a light vertical elastic with removing the posterior segmental arch wire.

3. Using a tooth positioner at the end of the treatment (Mitchell, 2007; Proffit et al., 2006).

Soft tissue factors

As an attempt to increase the stability of the treatment outcomes, teeth at the end of treatment should be in the natural zone, which is a balanced area between the cheeks, lips, and tongue. For instance, to reduce the relapse risk during the treatment of Class II division I cases, upper anterior teeth should be retracted to make them lie in the natural zone at the end of treatment. In the other hand, when teeth are moved out of the natural zone, the relapse tendency is increased, especially if the lower anterior teeth were over proclined or retroclined (Mitchell, 2007; Proffit et al., 2006).

Studies have found that remarkable changes in the arch form are more susceptible to the relapse due to the unbalanced natural zone and the increased pressure of soft tissues. In this context, changes in the inter-premolar width are more stable than the changes in the inter-canine and the inter-molar width, however, the inter-canine width changes have less stability after the treatment, therefore, relapse probability increases (Mitchell, 2007; Proffit et al., 2006).

Growth factors

Transverse growth, anteroposterior growth, and vertical growth patterns are considered to be main relapse causing factors as they tend to grow in their original patterns before the treatment. The transverse growth is finished first, thus, clinical problems associated with this type of growth are less compared with the other two types. Therefore, treatments of anteroposterior and vertical growth problems require more controlled management and retention to avoid relapse occurring (Van der Schoot et al., 1997).

Other factors of relapse

- Physiological changes in soft tissue with age.
- Expansion that changes the arch width.
- Bad diagnosis and failing to follow the treatment plan.
- Not treating the cause of malocclusion.
- Incorrect arch size and harmony.
- Incorrect axial inclinations.
- Tooth size disharmony (Singh, 2015).

2.2. Post-treatment relapse of mandibular anterior teeth

The mandibular anterior teeth are most susceptible to be relapsed. (Little, 1975) found that the post-treatment irregularity of the lower anterior teeth is sufficient evidence for the other malocclusion tendencies appearance. Additionally, 70% to 90% of the cases have undergone some degree of relapsing in the mandibular teeth, while the maxillary teeth have shown a lower affection. Nearly 40% of the untreated population ranged between 15 and 50 years of age exhibits clinically significant irregularities of the incisor, and 17% of the population shows severe amounts of relapse with 7mm and more of mandibular irregularity (Myser et al., 2013).

2.2.1 Factors affecting on relapse of mandibular anterior teeth

There are many factors that cause the instability of the mandibular anterior teeth post orthodontic treatment.

- Normal physiological responses.
- Changes of inter-canine and inter-molar width.
- Changes in arch length.

- Changes in dental arch form.
- Growth pattern.
- Role of developing third molars.
- Mandibular anterior bony support.

Normal physiological responses

Arch length and arch width both decrease by ageing, as a respond to the normal physiological process, which leads to changes in muscle tone in both treated and untreated patients. This normal physiological response continues to be active during the 20 to 30 years of age despite of the completed growth. However, after the age of 30, these physiological responses become less active (Little, 1999; Mitchell, 2007).

Changes of inter-canine and inter-molar width

The inter-canine and inter-molar widths in the mandibular arch are more susceptible for changes than in the maxillary arch. Additionally, it has been found that most of the mandibular anterior teeth relapses continue to occur even before the age of 30, and in some cases this relapse continues to the age of 50. In this context, changes in the inter-premolar width are more stable than the changes in the inter-canine and the inter-molar width, however, the inter-canine width changes have less stability after the treatment, therefore, relapse probability increases (Proffit et al., 2006; Mitchell, 2007).

Changes in arch length

The arch length increases during the orthodontic treatments due to the increase of the incisor protrusion as found in many previous studies. However, at the post-retention stage, protruded anterior teeth tend to return to its previous length while the crowding of lower anterior teeth increases. Also, the arch length and arch width tend to decrease in extraction cases post-treatment (Little, 1999; Freitas et al., 2004; Guirro et al., 2015).

Changes in dental arch form

The stability of the arch form increases if the original arch form is maintained during treatment. Therefore, remarkable changes in the arch form considered to be a cause for orthodontic treatment relapse (Little, 1999).

Growth pattern

(Freitas et al., 2004) found a relationship between the type of growth and relapse occurrence in the lower anterior teeth. Whereas patients with vertical growth patterns have more relapse tendency over patients who have horizonal growth patterns. Additionally, teenagers with ages ranging between 12 to 17 years and whom have vertical growth patterns have shown crowding more than teenagers with horizontal growth patterns (Sakuda et al., 1976).

Mandibular incisor crowding is related to skeletal growth pattern, whereas:

- The growth of the mandibular in Class III and normal patients is associated with the crowding increase of the mandibular incisors, that because the increase of the lip force on the lower teeth because of the forward mandibular growth.
- For skeletal open bite patients, the mandibular rotates downward and backward which also increases the lower anterior teeth crowding.

Preserving the stability of lower mandibular anterior teeth is an important step of the retention phase until the late growth of the mandibular is completed, which approximately finishes at the late teens in females, and until the beginning of 20s in males (Proffit et al., 2006).

Role of developing third molars

It has been said that the position and inclination of the third molars are affected by the growth and development of the face. Whereas the inadequate growth of the mandibular leads to the increase of lower incisors crowding and third molars impaction tendency. However, neither the eruption nor impaction of the third molars has a clinically significant influence on the stability of lower anterior teeth post-treatment, as several researches have shown. Therefore, the extraction choice of the third molars should not rely only upon the need to maintain teeth stability (Van der Schoot et al., 1997; Little, 1999).

Mandibular anterior bony support

The mandibular symphysis or labiolingual thickness is important for mandibular anterior teeth supporting, whereas thin labiolingual bony layers lead to an increased mandibular incisor movement and relapse occurrence. During orthodontic treatment, the narrow and high symphysis is suspended to extensive bone loss of cortical plates of labiolingual surface, as suggested by (Wehrbein et al., 1996). Additionally, long-face patients usually have thing and high mandibular symphysis, and short faces are associated with thicker symphysis (Siciliani et al., 1990). (Roth et al., 2006) found that when the labiolingual cortical bone is thin, the density of mandibular symphysis is low compared with thick cortical bone, therefore, the probability of relapse and instability of the mandibular incisors is higher for thin cortical bone cases.

Many side effects are associated with increased teeth proclination, i.e. alveolar bone defects, gingival recission, and root resorption. Another interesting result found by (Uysal et al., 2012) was that the relapse probability of the lower anterior teeth is higher in females than in males, due to the thinner cortical bone in females.

2.3. Retention after orthodontic treatment

2.3.1 Definition of retention

Retention is an important phase after the orthodontic treatment, aims to maintain the teeth stable in their correct position. Neglecting this phase can cause the teeth to return to its original position and thus, relapse occurrence. Almost all orthodontic treated cases undergo to some degree of relapse, therefore, removable, or/and fixed retainers are significant at the end of orthodontic treatment (Littlewood et al., 2006).

2.3.2 Necessity of retention

1. Providing an enough time to reorganize the periodontal and gingival fibers post-treatment.
2. Reducing the relapse probability in the treatment caused by uncompleted growth.
3. Keeping the teeth in their new corrected position until the neuromuscular adaptation is completed (Blake and Bibby, 1998).

Reorganization of the periodontal and gingival tissues

Teeth stability is affected by three basic equilibrium factors:

- Compressive forces from the tongue, lips, and cheeks.
- Dental occlusion forces.
- Periodontal fibers forces.

The periodontal ligament and alveolar bone are the dentition supporting structures that can withstand heavy force but only for a short time. For instance, during mastication, the fluid contained in the PDL space absorbs the force, and this prevents the soft tissues from being compressed while the alveolar bone is being bended. Therefore, teeth movement requires light and long-time forces to stretch the periodontal and gingival fibers and to change the natural zone balance between the lips, tongue, and cheeks. From this principle, the idea of teeth moving during the orthodontic treatment became from widening of the periodontal ligament space and disruption of the collagen fiber bundles that support each tooth (Proffit et al., 2006).

Prolonged imbalances in tongue lip-cheek pressures or pressures from gingival fibers that would produce tooth movement are resisted by "active stabilization” due to PDL metabolism. And the disruption of the PDL produced by orthodontic tooth movement will reduces or eliminates the active stabilization, which means immediately after orthodontic appliances are removed teeth will be unstable in the face of occlusal and soft tissue pressures (Proffit et al., 2006).

2.3.3 Principles of retention

1. The principle of retention is to prevent relapse occurrence by using flexible bonded lingual retainers or removable retainers that promote physiological flexible teeth movement during mastication until the reorganization of the periodontal ligament PDl is completed, and at the same time, the alveolar bone bends in a response to the heavy force of mastication (Proffit et al., 2006).
2. Twelve months is the minimum suggested interval for retention, because the gingival fibers have a low response to the reorganization (Proffit et al., 2006).
3. Finishing the treating of skeletal disproportions early requires the usage of functional appliances or extra oral forces such as the headgears or chin caps part-time at night, until the growth rate is decreased (Proffit et al., 2006).
4. For the cases when the tongue, lip and cheeks forces are unbalanced, permanent retention is required to prevent the inevitable relapse (Proffit et al., 2006).
5. The retention is important for almost all patients until the late growth of the mandibular is completed to maintain the stability of the lower anterior teeth alignment (Proffit et al., 2006).

2.4. Classification of retentions

Retainers are designed as either removable or fixed to meet the various needs. When choosing the retainer, the clinical situation and the level of patient cooperation must be considered (Phulari, 2011).

<u>Retainers can be classified as:</u>

1. Removable retainers.
2. Fixed retainers.

2.4.1 Removable retainers

Passive removable retainers are used after the orthodontic treatment to maintain teeth stability and are useful for patients with growth modifications (Proffit et al., 2006).

Types of removable retainers:

1. Hawley’s retainer.
2. Begg’s retainer.
3. Clip-on retainer/spring aligner.
4. Full arch Wrap-around retainer.
5. Vacuum formed retainer.
6. Positioners as retainers.

Vacuum formed retainer (VFR)

The thermoplastic copolyester sheets are used to make this type of removable retainers.

Advantage of vacuum formed retainer:

1. Provides high aesthetics.
2. More Economic.
3. Easily and quick to make.
4. Provide high retention especially for lower anterior teeth.

Disadvantages of vacuum formed retainer:

1. Achieving good teeth settling is difficult, due to its thicknesses over teeth surface.
2. VFR tends to crack and discolored after a few months of use.
3. Teeth are prone to decalcification when cariogenic drinks are consumed while using the VFR (Proffit et al., 2006; Mitchell, 2007).

Vacuum-formed retainer’s contraindications:

VFR is not advised to be use with patients have bad oral hygiene because of its plastic engaging the gingival underact of contact points, therefore, with bad oral hygiene, these underact obliterate with hyperplastic gingivae (Proffit et al., 2006; Mitchell, 2007; Reddy et al., 2010).

Comparison between Vacuum-formed retainer and Hawley retainers:

Teeth settling with Hawley's retainer is easier and faster than teeth settling with VFR, because the VFR completely covers the occlusal plane. Many studies found an increase in the number of posterior contacts when using a Hawley's retainer for retention. Additionally, VFRs are better to maintain the stability of lower anterior teeth than Hawley's retainers. Patients have more compliant with VFRs than with Hawley's retainers (Mitchell, 2007).

2.4.2 Fixed (bonded) retainers

Fixed lingual retainers consist of passive lingual wires. They are indicated to maintain the results of orthodontic treatment and hold the teeth in their new position especially the lower anterior teeth, until the bone and fibers reorganization is completed (Reddy et al., 2010).

Development of fixed retainers

The first tooth bond orthodontic attachments were introduced by (Newman, 1965). (Zachrisson, 1977) presented the importance of using the multi-stranded wires as lingual retainers for long-term retentions (Hegde et al., 2011; Ouejiaraphant and Thongudomporn, 2015).

Three generations of fixed retainers:

- The first generation:

  The first bonded retainer was made of 0.032 to 0.036-inch round blue-elgiloy wire with loops at each end of the wire to increase retention (Hegde et al., 2011; Ouejiaraphant and Thongudomporn, 2015).
- The second generation:

  The second generation was introduced in 1983 which replaced the round wire by a multi-stranded 0.032-inch wire (Hegde et al., 2011; Ouejiaraphant and Thongudomporn, 2015).
- The third generation:

  Two different types of lingual fixed retainers have been developed at the third generation. The first one is a 0.032-inch multistrand wire, bonded only to the canines.

The other type is a 0.0175-inch and bonded to all teeth lingual surfaces (Hegde et al., 2011; Ouejiaraphant and Thongudomporn, 2015).

Indications of fixed retainers:

1. Maintaining of mandibular anterior teeth stability until ending of late growth.
2. Preserving of the implant space.
3. Keeping the extraction space and diastema closure.
4. Permanent or semi-permanent retention of closure maxillary diastema (Proffit et al., 2006).

Advantages of fixed retainer:

1. Cooperation of the patient is not quite important.
2. Invisible and esthetic.
3. Avoids tissue irritation.
4. Used for permanent and semi-permanent retention.
5. Does not affect speech ability.
6. Reduces follow-up visits.

Disadvantages of fixed retainer:

1. Oral hygiene becomes more difficult especially for interproximal areas of the lower anterior teeth.
2. More difficult to be inserted and adapted.
3. Needs more time to be inserted (Singh, 2015).

Types of fixed retainer

1. Band and spur retainer.
2. Banded canine to canine retainer.
3. Bonded canine to canine retainer.
4. Rigid canine to canine retainer.
5. Flexible canine to canine retainers.
6. A-splint retainer.
7. Bonded lingual retainer for maintenance of a maxillary central diasteme.

8. Memotain: CAD/CAM lingual retainer.

❖ **Flexible canine to canine retainers.**

This type of lingual retainers is commonly used for maintaining anterior teeth stability, the flexibility of this retainer allows it to be attached to all anterior teeth without preventing the physiological teeth movement. The wire is made from 17.5 or 0.19-mil twist stainless steel wires (Figure 2.1) (Mitchell, 2007; Hegde et al., 2011).

Figure 2.1. Multi-stranded stainless-steel wire.

❖ **Memotain: CAD/CAM lingual retainer**

Memotain is a new type of fixed lingual retainers recently developed as an alternative to the traditional fixed lingual retainers such as the multi-stranded stainless-steal retainer. This retainer is made by a computer-aided design and computer-aided manufacturing facility, and its flexibility is high because is made of 0.014×0.014 rectangular NiTi. CAD/CAM lingual retainer is customized for each patient which gives it high ability to be adapted into teeth lingual surfaces (Figure 2.2).

Figure 2.2. CAD/CAM lingual retainer.

CAD/CAM lingual retainer fabrication:

1. Impression is taken either digitally or by Polyvinylsiloxane material.
2. Digitally designing of the wire by using a 3D program to produce customized lingual retainer with maximum adaptation to tooth anatomical surface.
3. Cutting the wire using CAD from nitinol blank.
4. Final step before placement of the lingual wire retainer is electro-polishing of the wire.

   Electro-polishing is an important procedure to make the wire smooth, clean, polished, and more resistant to microbial colonization, and moreover, rounding the sharp edges. Elector-polishing is the use of an electrolysis device to clean and form the surface of the wire. Electrolysis is done by emerging the wire into an ionic bath, then a current flows through the bath gradually to remove the material from the wire and form it in a microscopic scale.

Advantages of CAD/CAM lingual retainers:

1. Wire bending is done digitally because they are designed and manufactured by computers.
2. High fitting accuracy and adaptation to the lingual surface especially for interproximal areas.
3. Less tongue disturbing.
4. Durable, microbial colonization resistant, and better for gingival health.
5. Its high fitting and adaptation make its insertion easy.
6. The upper retainer avoids interference with the lower anterior teeth because it is digitally designed (Wolf et al., 2015; Kravitz et al., 2017).

2.5. Care of retainers

The lingual bonded retainers are more aesthetic and save for long-term using. The major patients bothering thing about fixed retainers is that the fixed retainer makes the oral hygiene difficult, especially for the interproximal area, which if well maintained could cause a potential periodontitis and caries. Therefore, patients must be well-educated about how to deal with the retainerto maintain their oral hygiene by showing them the correct use of either a dental floss that can pass under the wire or a small interdental toothbrush. Therefore, maintaining oral hygiene with removable retainers is easier than with fixed retainers as patients can remove the retainer and clean it by toothpaste and denture-tables (Mitchell, 2007).

3. MATERIALS AND METHODS

The present study was conducted on 60 participants, all had completed their orthodontic treatment in the orthodontic clinic at the Near East University, Northern Cyprus, after obtaining ethical approval (EK/870-2019). The first group consisted of 15 participants who received (0.012×0.018-in computer-aided design computer-aided manufacturing Nickel-titanium lingual wire (CAD/CAM LR), Robofix, Istanbul, Turkey). The second group consisted of 15 participants who received (0.017-in, twisted multi-stranded stainless-steel lingual wire (MSLR), American Orthodontics, Sheboygan, WI, US). The third group consisted of 15 participants who received (0.027×0.011-in single strand Nickel-free Titanium lingual wire (SSLR), Reliance, Chicago, IL, US), and the final group consisted of 15 participants who received (1mm, vacuum-formed removable retainer (VFR), Scheu Dental, Iserlohn, Germany). All retainers except CAD/CAM LR were constructed by an experienced dental technician in the clinic laboratory.

The inclusion criteria were the presence of all of the lower anterior teeth which had irregularities before treatment, all participants were treated with full-fixed appliances (0.018-in Roth bracket slot system), no retreatment, no circumferential supracrestal fiberotomy, and perfect alignment of the lower anterior teeth at the end of the treatment. On the other hand, the exclusion criteria were bad oral hygiene, history of periodontal diseases, consumption of antibiotic prophylaxis before a gingival and periodontal examination, taking medications that have side effects on the gingival health, pregnancy, diabetes, smoking, and orthognathic surgery cases. The fixed retainers were fitted immediately after debonding the brackets, while the participants who received the removable retainers were given the mandibular VFR immediately and asked to wear them permanently during the first six months. Furthermore, participants were recommended not to visit the dentist for scaling during the follow-up intervals.

This prospective study was conducted over a period of six months, and the digital impressions were taken by (CEREC Omnicam 3D intraoral scanner, Dentsply, Sirona, Pennsylvania, US) at three different intervals: immediately after the treatment (T_0), three months after the treatment (T_1), and six months after the treatment (T_2).

The following dental measurements were taken for all the impressions in each interval by the software (3Shape Ortho Viewer, 3Shape, Copenhagen, Denmark).

1. Irregularity index (IR): The summed value (in millimeters) for the displacement of the five anatomical contact points of the mandibular anterior teeth, as described by (Little, 1975) (Figure 3.1).

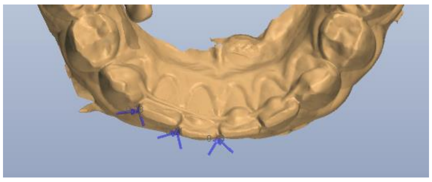

Figure 3.1. Measuring mandibular incisor irregularity.

2. Anterior dental arch length (ADAL): The perpendicular line connecting the most labial surface of the lower central incisors to the line between the labial anatomical contact point of the first and second premolars (Figure 3.2) (Rakosi et al., 1993).

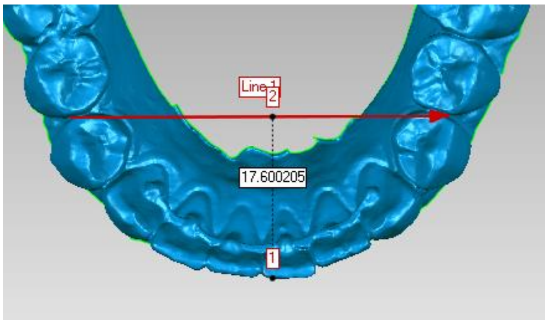

Figure 3.2. Measuring anterior dental arch length.

3. Inter-canine width (3-3 width): The distance between the cusp tips of the lower canines (Figure 3.3) (Little and Riedel, 1989).
4. Inter-molar width (6-6 width): The distance between the mesio-buccal cusp of the first lower molars (Figure 3.3) (Guirro et al., 2016).

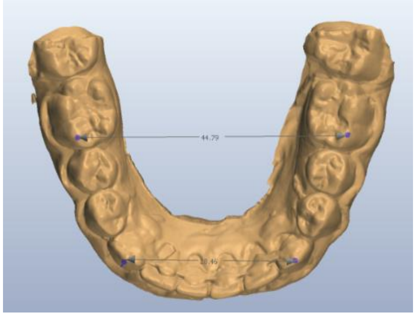

Figure 3.3. Measuring inter-canine and inter-molar widths.

At T_2, all participants had undergone periodontal examinations. The examination included plaque index (PI), gingival index (GI), bleeding on probing (BOP), and pocket depth (PD), (Appendix) (Löe, 1967; Newman et al., 2006). The posterior and anterior mandibular teeth except the second and third molars were examined including all teeth surfaces, namely the buccal (B), mesio-buccal (MB), disto-buccal (DB), lingual (L), mesio-lingual (ML), and the disto-lingual (DL) surface. All 3D model measurements and periodontal examinations were done by one researcher (M.B.A).

After two weeks, all models were re-measured to conduct an intraexaminer reliability test and determine the measurement errors, which returned excellent agreement scores with Cronbach's alpha coefficients between 0.99 and 1 for all groups. Additionally, to get more reliable periodontal examinations, (M.B.A) researcher was trained in the periodontal clinic at the same university before making any periodontal examination for the participants.

3.1. Sample size calculation

The sample size was calculated with G*Power software (Version 3.1.9.4 for Mac). The main outcome and hypothesis of the study was the changes in mandibular incisors irregularity, where a 0,05 mm difference between study groups with an estimated standard deviation of 0.1 mm and a statistical power of 80% with Type I error of 0.05 were considered as the calculation inputs. A minimum of 48 patients were calculated to be included in the 6-month follow-up, with 12 patients in each group. A potential dropout rate of 20% was estimated to occur during the research period. Therefore, the sample size was determined to be at least 56 patients (minimum 14 patients in each group).

3.2. Randomization procedure

Electronic randomization online software was used to generate random numbers for all participants based on inclusion and exclusion criteria and type of interventions (www.randomizer.org), which was performed while the patients' treatment was still ongoing prior to debonding. The random numbers generated for the participants were then randomly allocated into one of the four intervention groups equally using online software (www.randomizer.org) and were sealed in an opaque envelope that was prepared in advance by a complete different practitioner to ensure that both the participants and the authors were masked in order to avoid selection bias in our study. Furthermore, participants were randomly allocated into the four groups without differentiating between patients treated with extraction and non-extraction and results obtained from each group included both types of treatments, not as separate individuals. Lingual surfaces were blinded from the observer during the assessment of teeth stability in order to minimize measurement bias. However, blinding was not an option during the clinical periodontal examination.

The flow of participants through the trial is presented in the consort diagram shown in (Figure 3.4). The CAD/CAM LR group comprised 15 participants (6 males and 9 females) with a mean age of 20±6 years, where 4 of them were extraction cases (11 Class I and 4 Class II). The MSLR group comprised 15 participants (5 males and 10 females) with a mean age of 20±8 years, where 2 of them were extraction cases (12 Class I and 3 Class II). The SSLR group comprised 15 participants (4 males and 11 females) with a mean age of 20±7 years, where 3 of them were extraction cases (13 Class I and 2 Class II). Finally, the VFR group comprised 15 participants (2 males and 13 females) with a mean age of 18 years (minimum age of 13 years and maximum age of 27 years), where 3 of them were extraction cases (12 Class I and 3 Class II).

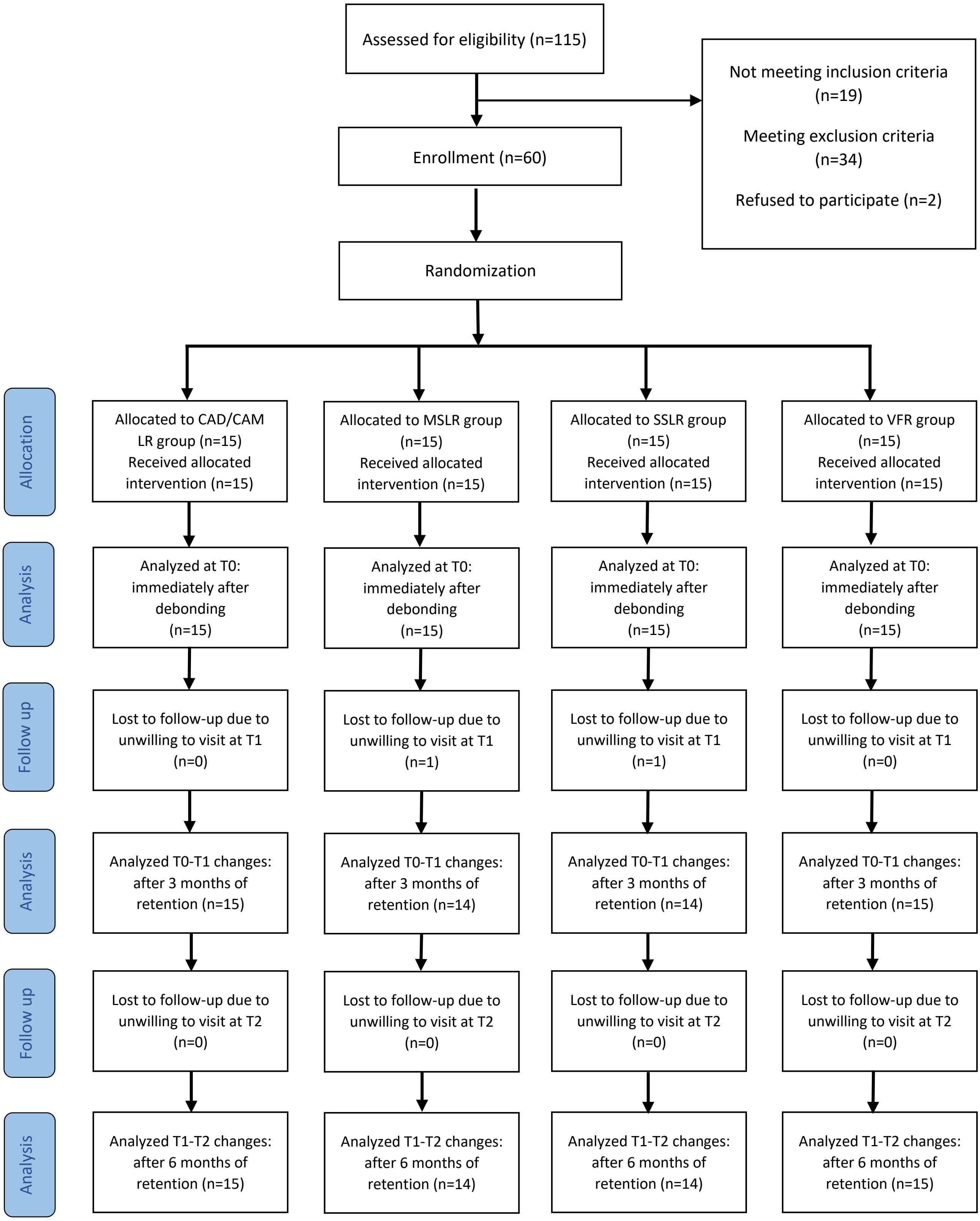

Figure 3.4. Consort diagram showing the flow of participants through the clinical trial. Computer-aided design computer-aided manufacturing Nickel-titanium lingual retainer (CAD/CAM LR), multi-stranded stainless-steel lingual retainer (MSLR), single strand Nickel-free Titanium lingual retainer (SSLR), and vacuum-formed removable retainer (VFR).

3.3. Statistical analysis

Descriptive statistics for all variables were calculated. All quantitative variables were represented with arithmetic mean and standard deviation. In order to evaluate the data distributions, the Shapiro-Wilk test of normality was performed. Since the data distributions for each variable and in each group were normal, parametric hypothesis tests were applied. For the comparison of periodontal measurements between the four independent study groups, One-Way Analysis of Variance (One Way ANOVA) was performed. In the case of statistical significance, the Tukey HSD post hoc test was applied to investigate the significance of pairwise group differences. For the repeated data were within (models-time effect) and intergroup differences are being compared, the Two-Way Repeated Measures Analysis of Variance test (Two Way RM ANOVA) was implemented. The Tukey multiple comparisons test was performed for pairwise group comparisons, for both independent intergroup and dependent intragroup analysis. Furthermore, in order to evaluate the reliability of the measurements, Cronbach's alpha coefficients were calculated for all groups and variables. Throughout the study, the statistical level of significance was set at 0.05. Prism for Mac (Demo Version 8.2.1) and SPSS for Mac (Demo Version 25.0.0) software packages were used for all statistical calculations.

4. RESULTS

4.1. Orthodontic treatment stability results

Statistical comparison was conducted intragroup (T_0, T_1, T_2) and intergroup (Table 4.2, 4.3). In terms of the irregularity of the lower anterior teeth, it was found that there were not statistically significant intragroup and intergroup differences (P>0.05), while the single strand Nickel-free Titanium lingual retainer (SSLR) group showed a higher irregularity according to the mean intragroup difference, which was 0.30mm (Table 4.1).

Table 4.1. Treatment stability outcomes for all groups at T_0, T_1 and T_2. (ANOVA) †, ‡

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		IR	3-3 width	6-6 width	ADAL
		Mean/SD/N	**Mean/SD/N**	**Mean/SD/N**	**Mean/SD/N**
First group (CAD\CAM LR)	T_0	0.00/0.00/15	26.43/2.60/15	45.42/4.71/15	16.52/1.31/15
	T_1	0.07/0.26/15	26.37/2.54/15	45.47/4.70/15	16.52/1.17/15
	T_2	0.26/0.65/15	26.33/2.55/15	45.54/4.69/15	16.59/1.15/15
Second group (MSLR)	T_0	0.00/0.00/14	26.12/2.79/14	44.25/2.40/14	16.04/1.25/14
	T_1	0.20/0.38/14	26.03/2.83/14	44.25/2.54/14	16.18/1.33/14
	T_2	0.22/0.41/14	26.03/2.79/14	44.27/2.64/14	16.27/1.29/14
Third group (SSLR)	T_0	0.00/0.00/14	25.78/1.13/14	44.52/4.14/14	16.51/1.16/14
	T_1	0.27/0.65/14	25.79/1.20/14	44.46/4.41/14	16.72/1.17/14
	T_2	0.30/0.71/14	25.71/1.20/14	44.35/4.28/14	16.73/1.13/14
Forth group (VFR)	T_0	0.00/0.00/15	26.43/2.02/15	43.09/2.70/15	16.46/1.31/15
	T_1	0.12/0.34/15	26.47/2.02/15	42.98/2.63/15	16.41/1.38/15
	T_2	0.20/0.44/15	26.43/1.92/15	42.96/2.67/15	16.36/1.47/15

† N: number of participants.
‡ SD: standard deviation

Regarding the inter-canine width, there was an intragroup statistical difference for the multi-stranded stainless-steel lingual retainer (MSLR) group between T_0 and T_1 with a P value of 0.048, whereas the inter-canine width had decreased and the mean difference was 0.10mm (Table 4.2). There was no intragroup statistical significance for the inter-molar width (Table 4.2). Higher stability of inter-canine widths and less irregularity of lower anterior teeth occurred in the vacuum-formed removable retainer group (VFR) according to the mean difference scores (Table 4.1). However, these differences in the means did not have any statistical significance. The anterior dental arch length showed an intragroup statistical difference for the MSLR group between

T_1 and T_2 with a P value of 0.045, whereas the anterior dental arch length increased by 0.09mm (Table 4.2). No intergroup statistical difference was observed regarding all conducted dental measurements (Table 4.3).

Table 4.2. Intragroup comparison of treatment stability outcomes for the ($\mathbf{T_0}$ $\mathbf{T_1}$), ($\mathbf{T_0}$ $\mathbf{T_2}$) and ($\mathbf{T_1}$ $\mathbf{T_2}$). (ANOVA followed by Tukey tests) [†,*].

	IR	3-3 width	6-6 width	ADAL
	Mean diff /P Value	**Mean diff /P Value**	**Mean diff /P Value**	**Mean diff /P Value**
First group (CAD\CAM LR)	(T_0 T_1) -0.07/0.503	0.05/0.486	-0.04/0.940	-0.006/0.999
	(T_0 T_2) -0.26/0.302	0.10/0.378	-0.12/0.800	-0.06/0.737
	(T_1 T_2) -0.18/0.357	0.04/0.422	-0.07/0.398	-0.06/0.259
Second group (MSLR)	(T_0 T_1) -0.20/0.162	0.09/0.048*	-0.002/0.999	-0.13/0.267
	(T_0 T_2) -0.22/0.140	0.09/0.076	-0.02/0.986	-0.22/0.078
	(T_1 T_2) -0.02/0.210	0.00/0.999	-0.02/0.961	-0.08/0.045*
Third group (SSLR)	(T_0 T_1) -0.27/0.293	-0.007/0.995	0.06/0.920	-0.21/0.070
	(T_0 T_2) -0.30/0.279	0.06/0.831	0.16/0.715	-0.22/0.122
	(T_1 T_2) -0.03/0.241	0.07/0.113	0.10/0.526	-0.01/0.946
Forth group (VFR)	(T_0 T_1) -0.12/0.376	-0.04/0.806	0.10/0.280	0.04/0.875
	(T_0 T_2) -0.20/0.200	0.00/0.999	0.13/0.260	0.09/0.709
	(T_1 T_2) -0.08/0.471	0.04/0.513	0.02/0.889	0.05/0.780

[†] Mean difference.
* Statistically significant at P < .05.

Table 4.3. Intergroup comparison of treatment stability outcomes. (ANOVA followed by Tukey tests) [†, ‡].

	IR	3-3 width	6-6 width	ADAL
	Mean diff /P Value	**Mean diff /P Value**	**Mean diff /P Value**	**Mean diff /P Value**
T_0	(G_1G_2) 0.00	0.31/0.989	1.17/0.828	0.48/0.748
	(G_1G_3) 0.00	0.65/0.812	0.90/0.946	0.01/0.999
	(G_1G_4) 0.00	0.00/0.999	2.32/0.368	0.06/0.999
	(G_2G_3) 0.00	0.34/0.973	-0.27/0.996	-0.46/0.746
	(G_2G_4) 0.00	-0.30/0.986	1.15/0.623	-0.41/0.822
	(G_3G_4) 0.00	-0.65/0.707	1.42/0.700	0.04/0.999
T_1	(G_1G_2) -0.12/0.749	0.34/0.985	1.22/0.816	0.34/0.881
	(G_1G_3) -0.19/0.728	0.58/0.853	1.01/0.931	-0.19/0.970
	(G_1G_4) -0.04/0.977	-0.10/0.999	2.48/0.306	0.11/0.995
	(G_2G_3) -0.07/0.985	0.23/0.991	-0.20/0.998	-0.53/0.671
	(G_2G_4) 0.07/0.937	-0.44/0.981	1.26/0.561	-0.23/0.967
	(G_3G_4) 0.15/0.869	-0.68/0.679	1.47/0.704	0.30/0.916
T_2	(G_1G_2) 0.03/0.997	0.30/0.990	1.27/0.801	0.31/0.896
	(G_1G_3) -0.04/0.997	0.61/0.838	1.19/0.890	-0.14/0.985
	(G_1G_4) 0.05/0.994	-0.10/0.999	2.58/0.276	0.22/0.965
	(G_2G_3) -0.08/0.981	0.31/0.980	-0.08/0.999	-0.46/0.742
	(G_2G_4) 0.01/0.999	-0.40/0.969	1.31/0.554	-0.09/0.997
	(G_3G_4) 0.09/0.970	-0.71/0.630	1.39/0.728	0.37/0.868

[†] Mean difference.
[‡] Statistically significant at P < .05.
G: indicates group.

4.2. Periodontal examination results

In order to establish the statistical outcomes and calculate the P value for each tooth and make comparisons between the four groups, two mean values were calculated for the buccal (B) and lingual (L) surfaces, which included the buccal (B), mesio-buccal (MB), disto-buccal (DB), and the lingual (L), mesio-lingual (ML), disto-lingual (DL) surfaces.

The statistical analysis of plaque index (PI) showed a statistical significance with P values of 0.017 and 0.030 for the lower-left first molar's lingual surface and the lower-right first premolar's buccal surface, respectively, as shown in (Table 4.4). The gingival index (GI) showed a statistical significance for the lower-left first premolar's lingual surface and the lower-left second premolar's lingual surface with P values of 0.011 and 0.014, respectively (Table 4.5, 4.8). No spontaneous bleeding was recorded anywhere within the groups. However, bleeding on probing (BOP) showed a statistical significance for the lower-left second premolar's buccal surface and the lower-right first premolar's buccal surface with P values of 0.039 and 0.025, respectively, as shown in (Table 4.6, 4.8). All pocket depth (PD) means were normal for all groups (≤3mm) and a statistical significance was found for the lower-left first molar's buccal surface, and the lower-right first molar's lingual surfaces with P values of 0.022 and 0.012, respectively. Additionally the lower-right first molar's buccal surfaces showed two statistically significant values between CAD/CAM LR and SSLR groups, and between CAD\CAM LR and VFR groups with P values of 0.018 and 0.009, respectively, as shown in (Table 4.7, 4.8). However, despite these significant P values, these surfaces were still in the normal range for the PD.

Additionally, the mandibular anterior teeth were assessed as a group in order to detect the overall effect of CAD/CAM lingual retainer on them and compare these results with other retainers' effects. The results showed that the CAD/CAM lingual retainer group has the lowest mean values regarding the PI, GI, and BOP (Table 4.9). However, the results did not have any statistical significance.

Table 4.4. Intergroup comparison of plaque index outcomes. (ANOVA) †, ‡, *.

Tooth	CAD\CAM LR, MV	MSLR, MV	SSLR, MV	VFR, MV	PV
36B	0.73	0.71	0.97	0.64	0.413
36L	0.99	1.02	1.18	0.64	0.025*
35B	0.31	0.28	0.42	0.31	0.863
35L	0.68	0.61	0.56	0.57	0.895
34B	0.13	0.35	0.33	0.28	0.595
34L	0.36	0.59	0.51	0.28	0.312
33B	0.48	0.61	0.40	0.37	0.685
33L	0.33	0.71	0.68	0.41	0.246
32B	0.33	0.37	0.71	0.39	0.413
32L	0.37	0.61.	0.83	0.35	0.202
31B	0.44	0.57	0.78	0.37	0.493
31L	0.33	0.71	0.85	0.35	0.193
41B	0.48	0.66	0.80	0.53	0.655
41L	0.37	0.71	0.85	0.42	0.178
42B	0.46	0.61	0.73	0.57	0.838
42L	0.39	0.61	0.78	0.59	0.319
43B	0.57	0.99	0.66	0.57	0.418
43L	0.39	0.76	0.73	0.48	0.220
44B	0.51	0.63	0.24	0.00	0.031[b]
44L	0.51	0.58	0.30	0.30	0.423
45B	0.28	0.38	0.23	0.24	0.773
45L	0.55	0.57	0.56	0.44	0.902
46B	0.70	0.49	0.78	0.55	0.457
46L	0.71	0.99	0.99	0.93	0.614

† MV: mean value.
‡ PV: P value.
* Statistically significant at P < .05.

Table 4.5. Intergroup comparison of gingival index outcomes. (ANOVA) †, ‡, *.

Tooth	CAD\CAM LR, MV	MSLR, MV	SSLR, MV	VFR, MV	PV
36B	0.93	0.90	0.78	0.68	0.550
36L	1.19	1.02	0.85	0.73	0.193
35B	0.57	1.02	0.56	0.68	0.141
35L	0.77	1.10	0.35	0.77	0.026*
34B	0.69	0.99	0.53	0.71	0.282
34L	0.72	1.09	0.38	0.76	0.021*
33B	0.77	0.95	0.54	1.08	0.075
33L	0.97	1.09	0.76	1.10	0.439
32B	0.86	0.88	0.64	0.88	0.701
32L	0.84	1.18	1.02	0.99	0.608
31B	0.68	0.83	0.76	0.91	0.827
31L	0.90	1.02	0.92	0.79	0.867
41B	0.71	0.87	0.73	0.84	0.889
41L	0.84	1.16	0.99	0.82	0.509
42B	0.66	1.04	0.85	0.88	0.604
42L	0.59	0.99	0.87	0.82	0.409
43B	0.68	1.04	0.95	0.84	0.487
43L	0.71	1.02	0.97	0.68	0.248
44B	0.45	0.84	0.58	0.94	0.143
44L	0.72	1.07	0.52	0.72	0.224
45B	0.53	0.88	0.40	0.75	0.146
45L	0.79	0.92	0.52	0.84	0.466
46B	0.71	0.85	0.78	0.59	0.723
46L	0.88	0.83	0.85	0.77	0.973

† MV: mean value.
‡ PV: P value.
* Statistically significant at P < .05.

Table 4.6. Intergroup comparison for bleeding on probing outcomes. (ANOVA) **)** [†, ‡, *].

Tooth	CAD\CAM LR, MV	MSLR, MV	SSLR, MV	VFR, MV	PV
36B	0.06	0.11	0.11	0.11	0.839
36L	0.26	0.45	0.25	0.15	0.196
35B	0.02	0.17	0.11	0.02	0.030*
35L	0.19	0.25	0.04	0.17	0.265
34B	0.11	0.21	0.07	0.12	0.501
34L	0.13	0.23	0.02	0.12	0.181
33B	0.11	0.21	0.07	0.24	0.125
33L	0.33	0.28	0.18	0.26	0.699
32B	0.13	0.16	0.14	0.19	0.934
32L	0.15	0.33	0.45	0.24	0.139
31B	0.08	0.14	0.26	0.19	0.457
31L	0.15	0.21	0.37	0.24	0.338
41B	0.08	0.11	0.23	0.26	0.278
41L	0.17	0.33	0.33	0.24	0.570
42B	0.08	0.30	0.35	0.42	0.140
42L	0.06	0.26	0.30	0.22	0.094
43B	0.04	0.21	0.30	0.26	0.078
43L	0.04	0.18	0.23	0.11	0.057
44B	0.00	0.10	0.05	0.27	0.028*
44L	0.18	0.33	0.08	0.08	0.147
45B	0.06	0.09	0.07	0.15	0.646
45L	0.22	0.21	0.11	0.22	0.777
46B	0.04	0.18	0.21	0.11	0.217
46L	0.19	0.14	0.21	0.24	0.796

[†] MV: mean value.
[‡] PV: P value.
* Statistically significant at P < .05.

Table 4.7. Intergroup comparison of pocket depth outcomes. (ANOVA) [†, ‡, *].

Tooth	CAD\CAM LR, MV	MSLR, MV	SSLR, MV	VFR, MV	PV
36B	1.93	2.13	2.04	1.64	0.025*
36L	2.06	2.14	1.85	1.95	0.468
35B	1.90	1.99	1.87	1.59	0.270
35L	1.81	1.84	1.61	2.04	0.164
34B	1.85	1.94	1.97	1.61	0.261
34L	1.55	1.87	1.66	1.81	0.267
33B	1.88	1.99	20.02	1.84	0.612
33L	1.66	1.78	1.76	1.72	0.875
32B	1.99	1.82	1.87	1.77	0.666
32L	1.59	1.73	1.59	1.55	0.716
31B	1.79	1.64	1.85	1.70	0.566
31L	1.53	1.59	1.40	1.44	0.567
41B	1.77	1.66	1.66	1.77	0.835
41L	1.39	1.66	1.47	1.44	0.353
42B	1.97	1.85	1.66	1.66	0.158
42L	1.68	1.71	1.44	1.46	0.249
43B	2.08	1.87	2.02	1.93	0.711
43L	1.86	1.76	2.04	1.73	0.423
44B	2.08	1.89	1.83	1.77	0.527
44L	1.93	1.84	1.63	1.85	0.641
45B	1.82	1.99	1.75	1.75	0.196
45L	1.88	1.90	1.87	2.02	0.850
46B	2.46	1.99	1.90	1.86	0.006*
46L	2.59	2.16	1.97	2.13	0.015*

[†] MV: mean value.
[‡] PV: P value.
* Statistically significant at P < .05.

Table 4.8. Intergroups statistical significances for periodontal outcomes (ANOVA followed by Tukey tests) †, *.

	Tooth /groups	Groups	Mean diff	P value
Plaque index	36L	G_3G_4	0.54	0.017
	44B	G_2G_4	0.63	0.030
Gingival index	34L	G_2G_3	0.70	0.011
	35L	G_2G_3	0.74	0.014
Bleeding on probing	35B	G_1G_2	-0.15	0.039
	44B	G_1G_4	-0.27	0.025
Pocket depth	36B	G_2G_4	0.49	0.022
	46B	G_1G_3	0.56	0.018
	46B	G_1G_4	0.60	0.009
	46L	G_1G_3	0.62	0.012

† Mean diff: mean different.

* Mean difference is significant at the 0.05 level.

Table 4.9. Intergroup comparison of lower anterior teeth for plaque index, gingival index, bleeding on probing, and pocket depth. (ANOVA) †, ‡, *.

	CAD/CAM LR, MV	MSLR, MV	SSLR, MV	VFR, MV	PV
Plaque index	0.418	0.6636	0.7386	0.4567	0.34
Gingival index	0.7747	1.0114	0.8364	0.8920	0.71
Bleeding on probing	0.1247	0.2321	0.2721	0.2433	0.18
Pocket depth	1.7720	1.7600	1.7343	1.6713	0.80

† MV: mean value.

‡ PV: P value.

* Statistically significant at P < .05.

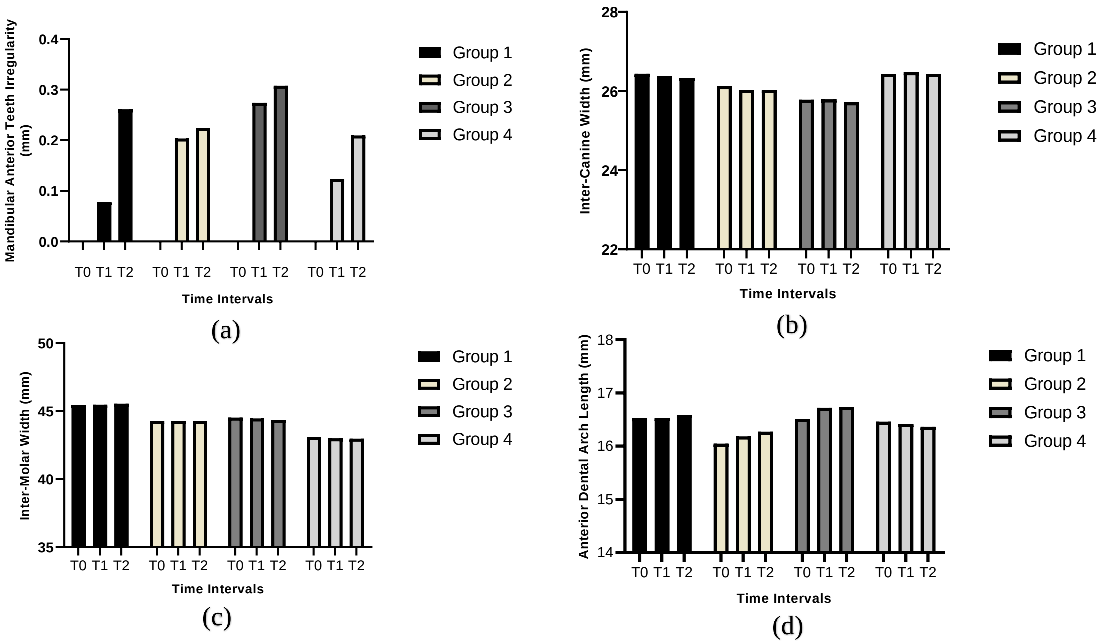

Figure 4.1. Changes of (a) the anterior teeth alignment, (b) inter-canine width, (c) inter-molar width, (d) Arch length with time.

5. DISCUSSION

Retention is an important phase of orthodontic treatment to maintain the stability of teeth after active treatment. Therefore, previous studies have discussed two methods to preserve this purpose. The first is the urgency to apply fixed and removable retainers. Many studies have produced opposite results regarding the most effective type of retainer (Atack et al., 2007; Al-Moghrabi et al., 2018). A short-term study found no clear evidence about the most effictive type of retention since the study results approved the same relapse level in mandibular anterior teeth for both fixed retainer and Hawley removable retainer and without statistically significant (Atack et al., 2007). However, a long term study with a four-year follow-up found that a lingual fixed retainer is more effective than the vaccum-formed removable retainer for maintaining mandibular anterior teeth stability (Al-Moghrabi et al., 2018). The second method to preserve treated teeth stability is approaching ideal treatment results, which can be reached by:1. Teeth interdigitate at the end of active treatment (Proffit et al., 2012). 2. Teeth positioned in the natural zone, which is the balance between the tongue, cheeks, and lips (Littlewood et al., 2017). 3. Preservation of the original arch form (Little, 1999; Sampson et al., 1995), inter-canine and inter-molar width (Adamek et al., 2015; Blake and Bibby, 1998). 4. Avoidance of an increase in the arch length by keeping the lower anterior teeth at the upright or slight retroclined position (Reitan, 1969; Singh, 2015). 5. Some adjunctive procedures to control the soft tissue rebound including fiberotomy, gingivectomy, and overcorrection (Proffit et al., 2012). The fifteen-year follow-up study of Myser et al. (2013) with a three-year retention period supported this idea by reacheing the result that following the orthodontic treatment guidelines leads to long-term stability.

The present prospective study aimed to evaluate the CAD/CAM fixed lingual retainer as a modern retainer and to compare it with traditional retainers as an attempt to determine the most effective retainer, which previous studies have presented conflicting results about. The participants were randomly allocated into four equal groups as an attempt to reduce the allocation bias among the groups, particularly since removable retainers are usually given to cooperative participants and participants who have less oral hygiene.

Studies have shown that dental measurements, especially precise anatomical contact points taken by digital models, have more accuracy, reliability, and validity than traditional manual measurements taken by plaster models (Goonewardene et al., 2008). Thus, the usage of digital models in this proposed study has reduced the error in the measurement method. As a trial to determine the best accurate dental measuring method, Kim et al. (2014) compared between plaster models, CBCT, and laser-scanned models, the laser-scanned models were the most precise models and can be used as clinical alternative scanning method. Although a difference was found between digital measuring and direct measuring on plaster, Fleming et al. (2011) concluded that this difference is clinically acceptable.

A systematic review concluded that studies have not agreed about the most effective type of retainers and the appropriate duration of retention that preserves long-term stability of treatment outcomes (Vandevska-Radunovic et al., 2013; Littlewood et al., 2006). Additionally, the present prospective study proved that all retainers used in the study, including CAD/CAM LR, showed the same failure rate in maintaining lower anterior teeth, inter-canine width, and arch length. Therefore, the ideal finishing and treatment results are not less important than choosing the retainer for maintaining the stability of teeth after orthodontic treatment.

The following studies discussed some important procedures that help increasing the stability of treatment results regardless of retainer type. Researchers and practitioners have concluded that the maximum tooth-contact in centric occlusion is a significant predictor for a long-term orthodontic treatment stability. Additionally, the maximum tooth-contact leads to directing the mastication force towards the long axis of the teeth, and as a result, decreasing the stress force on the teeth and periodontal tissues. Also, bringing the teeth to the fully interdigitated position at the finishing stage of the orthodontic treatment helps to maintain healthy periodontal tissues (Sari et al., 2009). Sari et al. has assessed the occlusal contact changes in the centric occlusion during retention periods for a one-year study. A comparison was done between Hawley removable retainers, fixed lingual retainers, and a control group with normal occlusions. The study had reached that the number of posterior contact points for both study groups had increased. However, the increase was higher for the bonded retainer group because the eruption and vertical mobility of posterior teeth are easier with bonded retainers, while the removable retainers partially or totally cover the occlusal surface. There were slight occlusal changes in the control group, which were interpreted due to the growth and development prosses. No changes were observed for all groups during the follow-up in the anterior contact points (Sari et al., 2009). Another study done by Dinçer et al. (2003) concluded that the ideal teeth settling should be achieved at the finishing stage during the active treatment. However, if teeth settling was postponed to the retention period, the retention appliance used must be designed to achieve the desired occlusion (Dinçer et al., 2003).

Many clinicians and researchers had concluded that the adjunctive procedures to control soft tissue rebound are very effective ways to prevent post-treatment relapse that caused by the gingival fibers' elasticity (Crum and Andreasen,1974). Crum et al. studied the effectiveness of the adjunctive gingival fibers surgery on maintaining the post-treatment position of teeth which have rotation tendency. The study found that even with successfully treated cases, there are relapse tendencies and teeth returning to their pretreatment positions, especially the teeth which were rotated prior to the treatment, therefore, the Circumferential supra-crestal fibrotomy (CSF) procedure showed positive results on keeping these teeth at their post-treatment positions.

It was established by many studies that the changes of the arch-form, arch length, and arch width during the active treatment lead to an increase of relapse probability and return the arch-form, arch length, and arch width to their pretreatment shape. In the 10-year follow-up study of De La Cruz et al. (1995), 87 Class I and Class II subjects had their four premolars extracted. A statistical difference was found during the orthodontic treatment in the arch-form of both groups. The return of arch form to its pretreatment shape continued to the post-retention period. The results found by Sampson et al (1995). did not agree with the assumption claiming that maintaining the original arch-form during the treatment will increase the stability of the dental arch, whereas De La Cruz et al.'s study did not find a difference in the relapse magnitude between Class I and Class II groups at the post-retention period, although the subjects of Class II had undergone to a greater change in the arch-form during the active treatment period. As a result, the study suggested that maintaining the original arch-form is not a guarantee for long-term stable results. Felton et al. (1988) studied the probability of arch-form returning to its pretreatment shape and found that 70% of the studied arches had return to their pretreatment shapes. Another study established by Joondeph et al. (1970) agrees with this result.

In the present study, the changes occurred during the active treatment were not measured since the aim of the present study was to observe the dental changes during the first six months of retention period. The results of this study prove that CAD/CAM LR does not have higher stability over other retainers regarding the inter-canine width (Figure 4.1b). Moreover, the inter-canine width decreases in all groups except in the VFR group which was relatively stable (Table 4.1). However, these changes of the inter-canine width did not show any statistically significant values between the groups (Table 4.3). Additionally, the inter-canine width of the MSLR group had decreased by 0.10mm with a statistically significant difference within the group (Table 4.2). These changes in the inter-canine width can be interpreted by the changes of the original width during treatment. Some studies agreed with the concept of maintaining the original dimensions of the inter-canine width is better for more treatment stability (Adamek et al., 2015; Glenn et al., 1987; Blake and Bibby, 1998). However, other studies did not support this concept (Taner et al., 2004). The findings of the present study agree with previous studies, which found a decrease in the inter-canine width in post-retention period (Shapiro, 1974). However, a long-term study found that the inter-canine width had decreased in both removable and fixed retainers with no statistical difference between them (Al-Moghrabi et al., 2018).

Shapiro et al. (1974) studied inter-canine width changes during, immediately after treatment, and ten years post-retention for extraction and non-extraction Class I and Class II, Division I and II cases. The results showed an increase in the inter-canine width during treatment for all groups, while the inter-canine width decreased in post-retention period. However, some inter-canine changes were maintained in Class I non-extraction and Class II, Division II extraction and non-extraction cases.

Shapiro et al (1974). concluded that in all groups, inter-canine width has a strong ability to return to its pretreatment dimensions, however, there is more ability to maintain the treatment dimensions of the inter-canine width for Class II, Division II cases. A meta-analysis applied over 26 studies, done by Burke et al. (1998) assessed the changes of inter-canine stability after treatment. The study found that the extraction procedure does not provide more stability in the inter-canine width compared with non-extraction cases. Furthermore, the study agrees with the concept of maintaining the original dimensions of the inter-canine width is better for more treatment stability.

Generally, changes in the inter-molar width after treatment are less compared with the inter-canine width. In the present prospective study, changes in the inter-molar width were different between groups (Table 4.1) (Figure 4.1c), these changes of the inter-molar width did not show any statistical intragroup and intergroup differences (Table 4.2, 4.3). However, CAD/CAM LR group showed a slight increase in the inter-molar width, while the inter-molar width was relatively stable in MSLR group, and finally, the inter-molar width decreased in both SSLR and VFR groups. This inter-molar width deviation between the groups could be a result of the random allocation of the study sample without differentiating between Class I and Class II malocclusion patients treated with extraction and non-extraction, therefore, results obtained from each group included both type of treatments, not as separate individuals. The results of the present study agree with previous studies (Shapiro, 1974). Many studies supported the concept that inter-molar width is relatively stable after orthodontic treatment especially in Class II cases (Glenn et al., 1987; Taner et al., 2004).

Previous studies have concluded that the inter-molar width in the non-extraction cases was increased during the treatment and was maintained in some cases; this increase of the width was maintained after treatment, while in other cases, it continued to increase (Shapiro, 1974; Glenn et al., 1987). However, in the extraction cases, the inter-molar width decreased during the treatment and continued to decrease post-treatment (Shapiro, 1974; Glenn et al., 1987). The long-term study of Shapiro found an increase in inter-molar width during treatment for Class I, Class II, Division I and II non-extraction case, while a decrease was found in inter-molar width during treatment for Class I, Class II Division I and II extraction cases. Furthermore, at post-retention period, the inter-molar width tended to decrease in all groups except in Class II, Division II which continued to increase by 0.3mm. Finally, Shapiro et al. concluded that non-extraction cases have more tendency to maintain the inter-molar width post-retention than extraction cases. On the other hand, Motamedi et al. (2015) also found an increase of the inter-molar width during treatment; however, this increased distance could not be completely maintained after treatment for the non-extraction, class I and class II cases. The study of Glenn et al. (1987) found a small amount of changes occurred during and after treatment regarding the inter-molar width, which supports the concept that inter-molar width is relatively stable after orthodontic treatment especially in Class II cases. Additionally, Glenn et al. found that 71% of the cases had an increase in inter-molar width during treatment and 60% of the cases had a decrease in inter-molar width at post-retention period (with mean of − 0.5mm).

Patients who receive fixed retainers are usually instructed to wear removable retainers permanently for the first four to six months, then only partially at night for the next six months. However, to avoid overlapping in the results of the present study, participants with fixed retainers were not prescribed to wear removable retainers. According to the results of the irregularity index, lower anterior teeth had shown crowding, whereas this crowding did not show any statistical intragroup and intergroup differences (Table 4.2, 4.3). This result supports previous studies, which concluded that relapses in lower anterior teeth will occur even with fixed or removable retainers (Atack et al., 2007; Al-Moghrabi et al., 2018). The CAD/CAM LR group showed a similar result with the other groups (Figure 4.1a), whereas three participants out of fifteen had a partial or complete failure of the CAD/CAM LR, which caused crowding of the lower anterior teeth. This contradicts the outcomes of the in-vitro study, which concluded that the CAD/CAM NiTi retainers have higher stability over the round twist stainless-steel retainers (Möhlhenrich et al., 2018). The present study proves that CAD/CAM LR has the same clinical failure rate of any fixed retainer, although it has a greater-fitting accuracy. In this context, no statistical differences were found between the removable and fixed retainer groups, which agrees with the short-term study of Attack et al. (2007) and disagrees with the long-term study of Al-Moghrabi et al. (2018). The one-year follow-up study of Attack et al. contained 58 patients divided into two equal groups; the first group received multi-stranded stainless-steel lingual retainers, and the second group received Hawley removable retainers. According to Little Index, the results showed relapses in the lower anterior teeth for both groups equally without statistically significant differences between them. On the other side, the long-term study of Al-Moghrabi et al. conducted over four years compared between the vacuum-formed retainer and the 0.017-inch coaxial stainless steel retainer, the results showed relapse occurrence in both groups, however, the median of irregularity index was higher in the removable retainer group than in the fixed retainer group, with a 2.37-mm and 0.85-mm respectively. Al-Moghrabi et al. concluded that the fixed retainers are more effective in maintaining the stability of lower anterior teeth compared with the removable retainers. This outcome can be interpreted as the patients become less cooperative over time.

An 8-year post-retention follow-up study conducted on 28 Class I and Class II, Division I non-extraction cases. According to Little Index for mandibular anterior irregularity, the mean of pretreatment incisor irregularity was 2.9-mm, whereas 64% of the cases had minor irregularity (less than 3.5-mm), and 36% had moderate irregularity (between 3.5 and 6.5-mm). At the 8th year post-retention follow-up, 86% of the cases showed a relapse with a minimum incisor irregularity, 12% were moderate, and 4% of the cases had a severe incisor irregularity (Glenn et al., 1987).

Little et al. (1981) studied the mandibular arch length changes on Class I, and Class II, Division I and II extraction cases for ten years. The results showed decreasing in arch length during treatment for all groups and it continued to decrease after retention with average over than 2mm. Glenn et al. (1987) evaluated the changes in the arch length for non-extraction Class I, and Class II, Division I cases, the study reached to an increase in arch length during treatment for 50% of the sample size but without statically significant values. However, there was statistically significant reduction in the arch length at post-retention period for 96% of the sample size with approximately -2.5mm reduction comparing to pre-treatment length.

Regarding the present study, the mandibular arch length did not show statistically significant differences between groups (Table 4.3). The mandibular arch length in CAD/CAM LR group remained relatively stable and decreased in VFR group during the retention period which agrees with other studies that found the arch length decrease at post-retention period (Little et al., 1981). However, the arch length increased in SSLR and MSLR groups, which disagrees with other studies (Glenn et al., 1987).

According to periodontal outcomes studies, the fixed lingual retainers seem to be the reason for the increased plaque accumulation, which leads to the availability of microbial colonization at retentive sites, which later calcifies. This negativity causes gingival inflammation and recession. The results of Storey et al. (2018) revealed that the bounded retainers are associated with more plaque accumulation and gingival inflammation when compared with VFRs. Generally, many factors can deteriorate oral health, such as pregnancy, diabetes, smoking, and other criteria. Along with patients who have bad oral hygiene, these criteria have been excluded in the present study in order to avoid the disproportion of the oral hygiene levels between the participants and in order to be able to detect the effect of the retainer along with no other effectors. The oral hygiene levels of the participants were assessed carefully according to Löe (1967) Plaque Index, which were observed during the three-week-interval visits for approximately four months when their orthodontic treatments were still ongoing. According to these observations, the researchers were able to decide whether the participants have sufficient oral hygiene skills or not.

At the six-month follow-up (T2) of this study, the overall effect of CAD/CAM LR on the lower anterior teeth including canines regarding PI, GI, and BOP had lower mean values compared with the other fixed and removable retainer groups, while PD was in the normal range for all groups (≤3mm). additionally, VFR group showed less plaque accumulation and BOP in lower anterior teeth compared with SSLR and MSLR groups. However, this effect did not show statistically significant values (Table 4.9). The study of Kanup et al. (2019) found a better effect on the oral health for the CAD/CAM LR when comparing it with the stainless-steel twistflex wire. The short-term observation in the present study concluded that the CAD/CAM NiTi retainer was associated with less plaque accumulation, gingival inflammation, and less bleeding points in the anterior teeth. This can be related to the material and design of the CAD/CAM NiTi wire, as well as other advantages such as electropolishing for the wire surface, which gives the wire smoothness, corrosion resistance, and less microbial colonization Kravitz et al. (2017). Because the VFRs were used in this study, all posterior teeth were assessed for the periodontal measurements to make a decent comparison between the VFRS and fixed retainers. In the present study no clinically significant differences between the VFRs and the other fixed retainers were observed regarding the posterior teeth except for a few statistical significances that were not clinically important for this short-term study (Table 4.8).

A randomized clinical trial done by Storey et al. (2018) assessed the periodontal health for 12-month follow-up immediately after bracket debonding, the study was implemented over 60 patients were divided into two groups, the first group received 0.019-in 3-stranded twistflex stainless steel lingual wire, while the second group received vacuum-formed removable retainer. Regarding plaque index, no statistical significance was found between the groups at debonding. At three-month follow-up, plaque index values were lower than at debonding for both groups, except for the lower anterior teeth region whereas the plaque index increased by 0.50 comparing with baseline. However, at 3 months, 6 months, and 12 months, plaque index was higher in the fixed lingual retainer group than in the vacuum-formed removable group, with a statistically significant difference between them. Regarding gingival index, no statistical significance was found between the groups at debonding. After 3 months using the retainers, gingival index values for both groups were lower than at baseline time. However, gingival health in the fixed retainer group was worse after 3 months in the upper teeth, and in the lower teeth after 6 months. Finally, calculus index had zero scores and without statistically significant differences between the two groups. Between 3 and 6 months, calculus index scores were higher in the fixed retainer group especially in the lower anterior teeth comparing with the removable retainer group but without statistically significant difference between them. After one year of retention, the above results conclude that the fixed lingual retainer is associated with more plaque, calculus accumulation, and gingival inflammation comparing with the vacuum-formed removable retainer (Storey et al., 2018).

The findings of the present study agree with Storey et al. (2018) results since VFR group during the six-month follow-up of this study showed less plaque accumulation in the lower anterior teeth comparing with the other fixed lingual retainer groups, except in CAD/CAD LR group which showed the best results. However, this difference between groups was not statistically significant. Additionally, VFR group did not show the best results regarding the gingival index comparing with the fixed retainers, which disagrees with Storey et al. (2018), and agrees with the long-term study of Al-Moghrabi et al. (2018) which found that both fixed and removable retainers are associated with similar levels of gingival inflammation.

Millet et al. (2008) found better gingival health and less bleeding after one year of completed orthodontic treatment and wearing either fixed or removable retainer, however, the better improvement was associated with the removable retainer. Also, two studies of Rody et al. found an increase in plaque accumulation and more gingival inflammation with the patients using fixed retainers comparing with removable retainers and with patients who did not use any type of retainers. However, this difference was not clinically significant (Rody et al., 2011; Rody et al., 2016). A twenty-year follow-up study found no negative effect of the bounded retainer on periodontal health, although there was more tendency for plaque and calculus accumulation (Booth et al., 2008). Artun (1984) interestingly found a probable positive effect on oral hygiene and gingival health caused by the patient's increased motivation and attitude gained during the orthodontic treatment period.

Since the CAD/CAM NiTi retainers have been recently developed, a short-term study was necessary to investigate the impact of CAD/CAM NiTi lingual retainers on the stability of the mandibular anterior teeth along with the periodontal health. Nevertheless, to make a basis for long-term future studies, further studies are advised to use more flexible CAD/CAM NiTi 0.014×0.014-inch wires as an attempt to decrease the failure rates.

6. CONCLUSION

No statistically significant differences were found between the CAD/CAM NiTi retainer and other retainers regarding the clinical failure rate. Additionally, the CAD/CAM LR has the same effect on maintaining the mandibular anterior teeth stability compared with the other types of fixed and removable retainers, although it has greater fitting accuracy. The CAD/CAM LR showed less plaque accumulation and gingival inflammation on the anterior teeth compared with other retainer types. However, this did not appear to have a clinically significant effect on periodontal health in this short-term study.

This prospective study concluded that all retainer types have the same failure rate on preserving teeth stability. Therefore, the ideal finishing and treatment results are not less important than choosing the retainer for maintaining the stability of teeth after orthodontic treatment.

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Appendix. Periodontal examination recordings.

	Index system	Additional details
The Löe Plaque Index (PI) (Löe, 1967).	0: No plaque. 1: A film of plaque adhering to the free gingival margin and adjacent area of the tooth. The plaque may only be recognized by running a probe across the tooth surface. 2: Moderate accumulation of soft deposits within the gingival pocket, on the gingival margin and/or adjacent tooth surface, which can be seen by the naked eye. 3: Abundance of soft matter within the gingival pocket and/or on the gingival margin and adjacent tooth surface.	
The Löe Gingival Index (GI) (Löe, 1967).	0: Normal gingiva 1: Mild inflammation: slight change in color, slight edema, No bleeding on probing. 2: Moderate inflammation: redness, edema, Bleeding on probing. 3: Severe inflammation: marked redness and edema, Ulceration, tendency to spontaneous bleeding.	
Bleeding on Probing (BOP)	0: No bleeding. 1: Present of bleeding.	
Pocket Depth (PD) (Löe, 1967; Newman et al., 2006).	PD ≤ 3mm: No pocket PD > 3mm: pocket is present	PD: Distance extents from the free gingival margin to the bottom of the gingival sulcus. Williams periodontal probe is used to measure PD

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